Repeatability of aerial surveys

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ABSTRACT

In order to monitor population trends through space and time, aerial surveys need to provide density estimates that are a constant proportion of the true population density and are therefore repeatable. Previous work has identified factors that affect the visibility of kangaroos from fixed-wing aircraft and the relative contribution of these factors to the variation in counts. However, this work has relied on repeated surveys of a population of constant size. The development of accurate survey methods using helicopters has allowed the bias in fixed-wing surveys to be determined directly. Bias can therefore be estimated and assessed between areas and over time. Comparisons of kangaroo density estimated by these two aerial survey methods were made over 1991–97 near Blackall in central-western Queensland. Estimates of bias declined with increasing density for red kangaroos *Macropus rufus*, were relatively constant for eastern grey kangaroos *M. giganteus* and were highly variable for common wallaroos *M. robustus*. Nevertheless, medium-term population trends for the two kangaroo species were moderately well tracked. Currently, correction factors for fixed-wing surveys are applied at the scale of a 1 km² survey unit or a transect line of many units. These factors made some improvement to repeatability in this study, but the resultant density estimates remained biased. Correcting for bias on a regional scale may be more appropriate.

INTRODUCTION

Broad-scale aerial surveys of kangaroos using fixed-wing aircraft serve three purposes for kangaroo management in Australia. Firstly, they provide absolute estimates of abundance from which a quota can be determined to allow harvesting for a sustained yield. Secondly, they describe the distribution of kangaroos over an area. Thirdly, they identify any trends in the kangaroo population over time. For the first purpose, an accurate (= unbiased) estimate of density is required, and the ability of aerial surveys to do this has been discussed by Cairns (1999). For the second and third purposes, aerial surveys only need to be precise. To achieve this, they need to be repeatable over time and in different areas. Furthermore, the sampling strategy must account for the dispersion of individuals in the population to ensure the sampling variance is of an acceptable magnitude. This paper deals mainly with temporal repeatability, but the concerns for spatial variation in bias, also examined by Cairns (1999), are almost identical.

FACTORS INFLUENCING REPEATABILITY

Repeatability generally refers to constancy of bias among samples. A monitoring technique is repeatable if any proportional difference in population size between any two areas or times is reflected in the same proportional difference in the index derived by that technique. Hence, it is assumed that aerial counts of kangaroos increase linearly from the origin as true density increases. Southwell (1989) distinguished repeatability from precision; the latter being defined as variation arising from sampling error. However, strictly speaking, the precision of an estimate will be determined by both the variation inherent in the technique (repeatability) and the variation arising from sampling.

To assess repeatability, aerial surveys may be flown over a population of constant size, but under a range of survey conditions. The similarity in the density estimates returned by these surveys will be one measure of the technique's repeatability. In this way, numerous studies have examined the influence that a number of factors have on repeatability. Many of these studies were reviewed by Southwell (1989). Caughley (1989) identified several factors that influence repeatability and the action that is taken to address this influence or, alternatively, the assumptions that are made. This has been summarized in Table 1. Essentially, these factors affect visibility and can vary between surveys. Visibility will be a function of kangaroo behaviour, the immediate habitat of the kangaroos and the immediate environment of the observer. There will be interactions between these three variables. For many years now, aerial surveys of kangaroos have been conducted at a fixed height, strip width and speed, in generally sunny, calm conditions within the three hours either side of darkness during the winter months (Southwell 1989) and with trained observers (Beard 1999). Some factors can be controlled at their extremes, but at other times they can only be randomized, thereby contributing to residual noise. Other factors, such as side-of-plane and time from darkness on a

Table 1. Factors that affect repeatability in aerial surveys of kangaroos. Factors marked with an asterisk influence kangaroo behaviour and habitat use. Other factors affect the immediate environment of the observer. Adapted from Caughley (1989).

Factor	Action or assumption
Height above ground Speed Strip width Time of day* Season (calendar month) Observer	Standardized
Shadow intensity Flight direction Cloud cover Turbulence Wind speed* Rain	Standardized to avoid extremes, otherwise randomized
Side-of-plane Time of day (fine)*	Randomized
Vegetation cover* Temperature*	Corrected
Kangaroo density	Relationship with aerial counts assumed to be linear

fine scale (e.g., from hour-to-hour), can also only be randomized.

Two related factors that can be neither randomized nor standardized are vegetation cover at a scale >1 km^2 and temperature; the latter affecting kangaroo behaviour including posture, activity and finer scale habitat use. Aerial survey counts are usually adjusted by correction factors to account for the influence of these factors.

CORRECTING FOR BIAS

Correcting for differences in sightability of kangaroos in different habitats involves assessing the vegetation cover of the area where sightings are made and adjusting the counts accordingly. Aerial counts of kangaroos can be corrected at a number of spatial scales.

Regional scale (>1 000 km^2)

This is generally the scale at which the assessment of bias is made. Surveys, such as those described by Cairns (1999) and below, are conducted using fixed-wing aircraft across large areas where a more accurate estimate of density has been obtained. However, vegetation across large areas is rarely homogeneous, so any correction factor will be insensitive to shifts in habitat use. Furthermore, altered behaviour patterns, such as a higher proportion of stationary kangaroos, or more kangaroos seeking shelter or smaller group sizes, will result in variable bias. Nevertheless, correcting for bias at a broad scale will probably ensure some assessment of regional variation in bias (i.e., spatial repeatability) which has been limited until now (Southwell 1989; Pople *et al.* 1998a). Correction factors that are currently applied at finer scales have been developed from a small number of regions and then extrapolated outside these regions.

Scale of a survey unit (1 km^2)

Currently, corrections for bias are made at either the scale of a 5 km × 0.2 km survey unit or a transect line comprising many units. Regions can be subdivided into broad habitat types (e.g., structural vegetation types) and survey units or even parts of survey units allocated to them. Ideally, the overall survey effort could be allocated to habitat-based strata in proportion to the population within each stratum. Assessment of bias usually relies on aerial counts being compared with an estimate of absolute density in blocks of homogeneous vegetation. However, such corrections will still be insensitive to some shifts in habitat use within units and to changes in behaviour, but counts can also be corrected for temperature. Bayliss and Giles (1985), in western New South Wales, and Caughley (1989), in southwestern Queensland, found that counts required adjustment upwards when temperatures at survey height were >15°C.

Scale of a sighting (0.001 km^2)

In theory, this is the appropriate scale to correct aerial counts of kangaroos. However, in practice, it is difficult to implement. Correction factors would need to be developed for aspects of the immediate habitat (e.g., within a 20 m radius) of each sighting and possibly the behaviour of animals (e.g., hopping, standing or lying down) and applied to each sighting. These could be determined from double counting. However, Caughley and Grice (1982) estimated from simulations that double-count estimates were excessively negatively biased where correction factors were >2.2. If this is generally true, then some assessment of the effects of kangaroo behaviour and habitat use on sightability would be possible with this method, but restricted to situations where sightability is relatively good, such as counts in 100 m strip transects and possibly counts of red kangaroos in 200 m strip transects (Cairns 1999). Pople *et al.* (1998b) used this technique successfully for correcting counts of feral goats from fixed-wing aircraft. Goat herd size significantly influenced sightability, but vegetation cover did not, making corrections of counts relatively easy.

AN ASSESSMENT OF REPEATABILITY

Comparing density estimates of a population of constant size under a range of survey conditions provides only some assessment of repeatability. Ideally, true density needs to be known so that constancy in bias can be assessed over time and between areas (Pollock 1995). Helicopter surveys using line transect methods return reasonably accurate and repeatable estimates of density for red kangaroos *Macropus rufus* and eastern grey kangaroos *M. giganteus*, but still underestimate common wallaroo *M. robustus* density by a factor of 2–3 (Clancy *et al.* 1997). This has allowed an assessment of bias in surveys of kangaroos using fixed-wing aircraft by flying both types of aircraft almost simultaneously over identical transect lines, leading to the development of regional correction factors (Pople *et al.* 1998a). Comparisons repeated over time provide an assessment of temporal repeatability.

Surveys of kangaroos by both fixed-wing aircraft (using 100 m and 200 m strip transects) and helicopters were conducted during 1991 to 1994 and 1997 over a large area (7 500 km^2) near Blackall in central-western Queensland. Standard survey methods for both platforms were employed (Pople *et al.* 1998a; Clancy 1999). Vegetation cover is relatively heterogeneous at Blackall, comprising partially cleared woodlands with large areas of fallen timber and regenerating vegetation. Pasture conditions during the study period generally declined from 1991 to 1994, but pasture was well above average during 1997. The three main commercially harvested species of kangaroos — red kangaroos, eastern grey kangaroos and common wallaroos — are all abundant in the area where they are also heavily harvested. Such a mixture of species at high densities, coupled with the patchy and temporally variable environment, increases the potential for variable bias in kangaroo surveys. In particular, there would have been changes in both the distribution or amount of food over the study period leading to changes in habitat use unrelated to temperature (Bayliss 1987; Hill *et al.* 1987).

Trends in the kangaroo populations at Blackall described by both fixed-wing and helicopter surveys are shown in Figure 1. The densities of all species based upon fixed-wing counts were lower than those estimated by helicopter surveys. Assuming the helicopter counts were equivalent to true density, correcting the fixed-wing counts of red kangaroos and eastern grey kangaroos using correction factors developed by Caughley *et al.* (1976) and Caughley (1989), still resulted in underestimates (Cairns 1999). The average bias from these surveys can be converted into average correction factors and these are presented in Table 2. Notably, the average correction factor for red kangaroos in Table 2 is higher than that reported by Cairns (1999) from the single survey at Blackall in 1992 (3.49 cf. 2.63). The observed year-to-year variability of the red kangaroo correction factors (Table 2), reflected in the coefficient of variation (CV), highlights the need to base correction factors on comparisons spanning a number of years and to recognize that correction factors are estimates with associated errors. As Barnes *et al.* (1986) pointed out, both error from sampling variation and that associated with the correction factor need to be incorporated into the standard error of density estimates.

For eastern grey kangaroos, correction factors for 200 m strips were much higher, but less variable, than those derived for red kangaroos. Year-to-year variation in correction factors for eastern grey kangaroos was much greater for the narrower strip, despite the smaller bias (Table 2). For red kangaroos, there was some reduction in variability of bias for the 100 m strip compared with the 200 m strip. Using "corrected" density estimates (i.e., corrected 200 m in Table 2) for red kangaroos and eastern grey kangaroos resulted in some improvement in repeatability as indicated by the variation in the correction factor that was still required to bring these corrected fixed-wing counts into line with the helicopter counts. Wallaroo correction factors were particularly variable and the bias was particularly large considering that wallaroo densities estimated by helicopter surveys are still underestimates of true density.

The relationship between kangaroo density estimated by fixed-wing and helicopter surveys

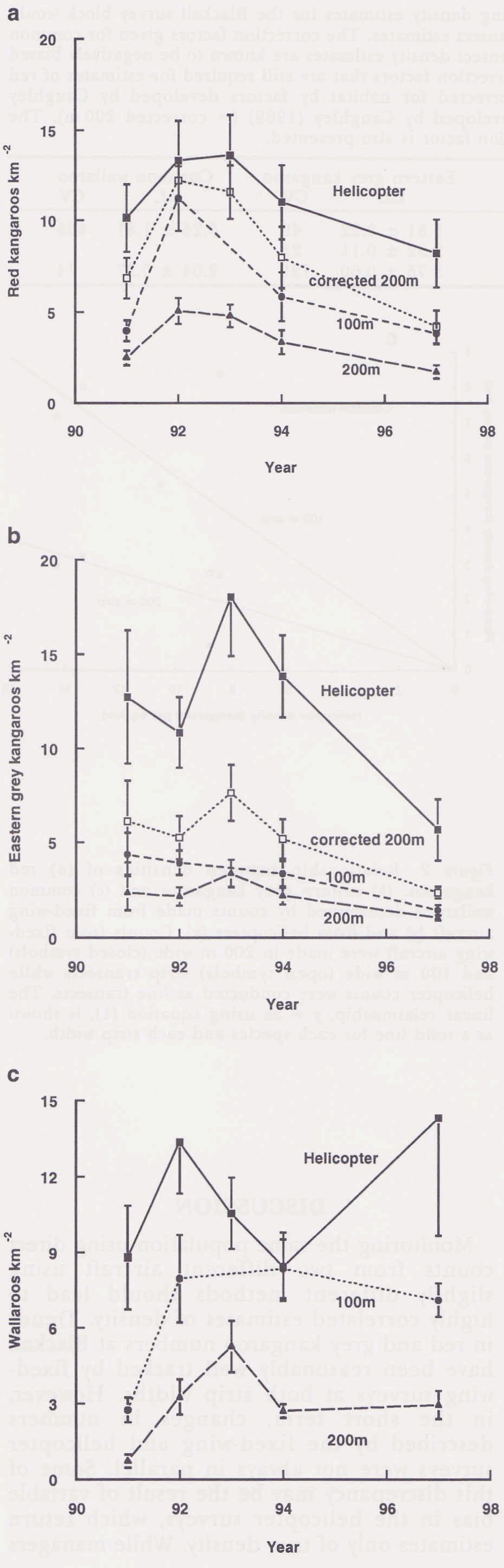

Figure 1 (left). Trends in the density of (*a*) red kangaroos, (*b*) eastern grey kangaroos and (*c*) common wallaroos on the Blackall survey block over 1991–97. Surveys were conducted along the same transect lines by helicopters using line transect method and by fixed-wing aircraft using strip transects of two different widths, 100 m and 200 m. Also shown are fixed-wing estimates for red kangaroos and eastern grey kangaroos counted in 200 m strip transects that have been corrected for habitat by factors developed by Caughley *et al.* (1976) and corrected for temperature by a factor developed by Caughley (1989) (= corrected 200 m).

can be explored further using regression analysis. Scatterplots of these relationships are shown for each species in Figure 2. Curvilinearity can be formally tested by expressing the relationship in the form, $FW = aHLT^b$, where FW is fixed-wing density, HLT is helicopter density and a and b are constants. Transforming both variables to natural logarithms gives the relationship the linear form,

$$\ln FW = \ln a + b \ln HLT \tag{1}$$

which is amenable to ordinary least squares regression analysis. Curvilinearity can be assessed with a test of the null hypothesis that the slope of the regression line will be one (i.e., b = 1), and the intercept can be used to calculate a correction factor (1/a). A correction factor calculated in this way is equivalent to the geometric mean bias and may be more appropriate than one derived from arithmetic mean bias (Table 2), particularly when the data are strongly right skewed. An alternative method is to use the untransformed data and force a simple linear regression through the origin and calculate the correction factor as the reciprocal of the regression coefficient (e.g., Cairns 1999). This may be appropriate when there are imprecise estimates of low densities whose influence can be greatly reduced in this way.

For red kangaroos, b was significantly >1 for counts in 200 m strips that were either uncorrected ($b = 2.13$, $t_3 = 7.28$, $P < 0.01$) or corrected ($b = 2.06$, $t_3 = 9.70$, $P < 0.01$). The relationship between counts of red kangaroos in 100 m strip transects with helicopter counts was not significantly curvilinear ($b = 2.25$, $t_2 = 1.72$, $P > 0.2$) despite b >> 1, due to a large scatter in the small sample (Fig. 2a). The data for red kangaroos suggest a bias that declines with increasing density. Forcing b = 1, yields correction factors (= 1/a) of 3.41 ± 0.57 for counts in 200 m strips and 1.87 ± 0.69 for counts in 100 m strips.

For eastern grey kangaroos, there was no significant curvilinearity for counts in 200 m strips that were either uncorrected ($b = 0.97$, $t_3 = 0.26$, $P > 0.5$) or corrected ($b = 0.99$,

Table 2. Correction factors (c.f. ± s.e.) by which the fixed-wing density estimates for the Blackall survey block would need to be multiplied in order to equal the helicopter line transect estimates. The correction factors given for common wallaroos, however, are conservative, as the helicopter line transect density estimates are known to be negatively biased by a factor of 2–3 (Clancy *et al.* 1997). Also shown are the correction factors that are still required for estimates of red kangaroos and eastern grey kangaroos that have been corrected for habitat by factors developed by Caughley *et al.* (1976) and corrected for temperature by a factor developed by Caughley (1989) (= corrected 200 m). The coefficient of variation (CV = s.d./c.f. × 100) of each correction factor is also presented.

Period	Strip width	Red kangaroo c.f.	Red kangaroo CV	Eastern grey kangaroo c.f.	Eastern grey kangaroo CV	Common wallaroo c.f.	Common wallaroo CV
91–94, 97	200 m	3.49 ± 0.38	85	5.51 ± 0.22	49	5.26 ± 1.81	405
91–94, 97	corrected 200 m	1.42 ± 0.15	34	2.32 ± 0.11	25		
91, 92, 94, 97	100 m	2.05 ± 0.27	54	3.75 ± 0.60	120	2.04 ± 0.37	74

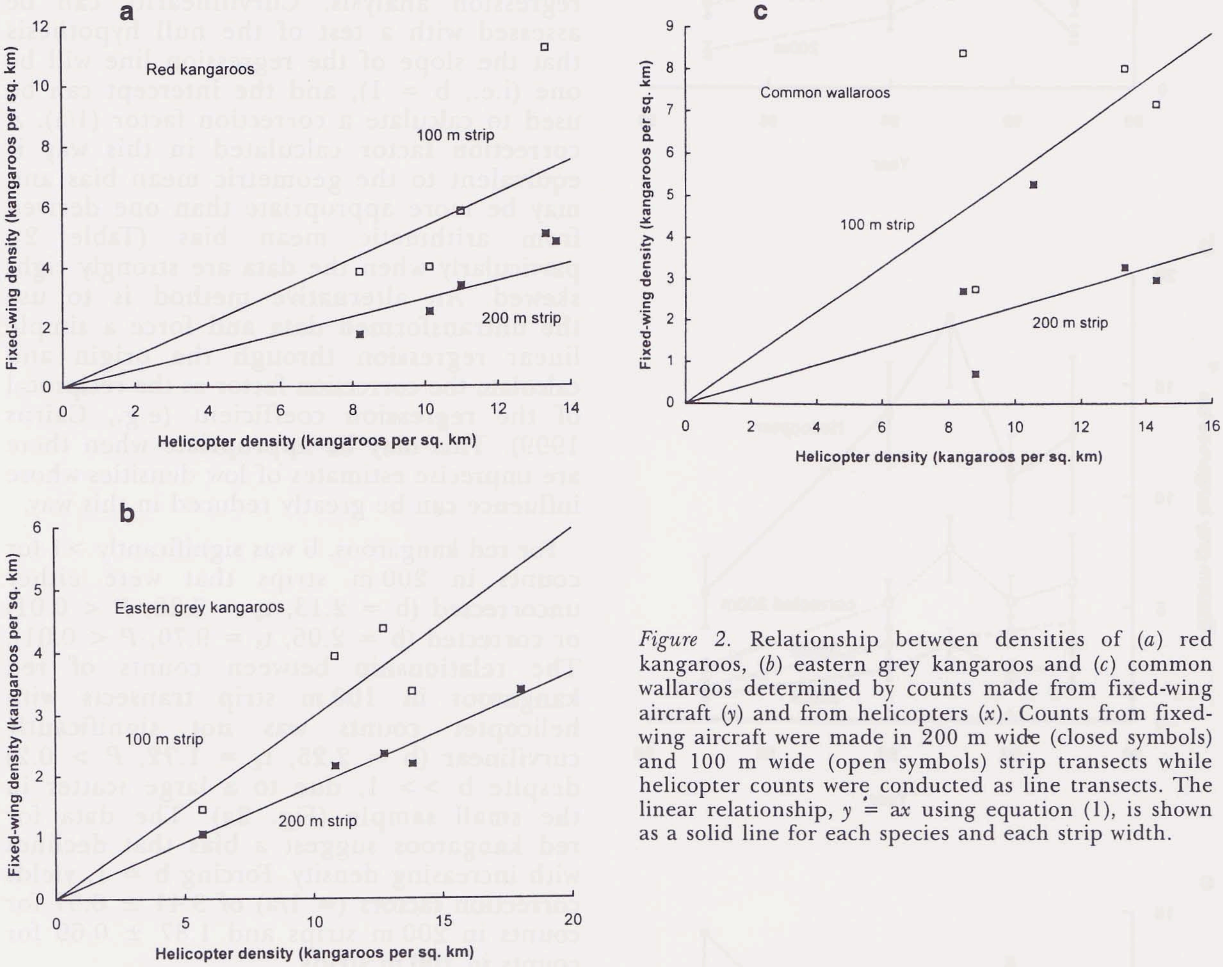

Figure 2. Relationship between densities of (*a*) red kangaroos, (*b*) eastern grey kangaroos and (*c*) common wallaroos determined by counts made from fixed-wing aircraft (*y*) and from helicopters (*x*). Counts from fixed-wing aircraft were made in 200 m wide (closed symbols) and 100 m wide (open symbols) strip transects while helicopter counts were conducted as line transects. The linear relationship, $y = ax$ using equation (1), is shown as a solid line for each species and each strip width.

t_3 = 0.07, $P > 0.5$) or for counts in 100 m strips (b = 1.15, t_2 = 0.45, $P > 0.5$). Forcing b = 1, yields correction factors of 5.49 ± 0.49 for counts in 200 m strips and 3.38 ± 0.61 for counts in 100 m strips.

For common wallaroos, there was no significant curvilinearity for either 200 m strips (b = 1.408, t_3 = 0.25, $P > 0.5$) or 100 m strips (b = 0.82, t_2 = 0.15, $P > 0.5$), but this was not surprising given the high degree of scatter (Fig. 2c). Forcing b = 1, yields correction factors of 4.33 ± 0.87 for counts in 200 m strips and 1.82 ± 0.81 for counts in 100 m strips.

DISCUSSION

Monitoring the same population using direct counts from two different aircraft using slightly different methods should lead to highly correlated estimates of density. Trends in red and grey kangaroo numbers at Blackall have been reasonably well tracked by fixed-wing surveys at both strip widths. However, in the short term, changes in numbers described by the fixed-wing and helicopter surveys were not always in parallel. Some of this discrepancy may be the result of variable bias in the helicopter surveys, which return estimates only of true density. While managers can place reasonable confidence in the medium to long-term trends described by aerial survey estimates, slight short-term population fluctuations should be interpreted cautiously. From the data presented here, major year-to-year fluctuations, such as declines following drought would be readily detected by fixed-wing aerial survey. The period of this study included years of drought and plenty, but any shift in habitat use by animals did not overly influence bias.

While repeatability seems acceptable for eastern grey kangaroos at Blackall, bias was still variable for red kangaroos. Again, some of this variation will come from the helicopter surveys. Clancy *et al.* (1997) reported a poorer fit to the relationship between helicopter counts and walked line transect counts for red kangaroos compared with eastern grey kangaroos. The suggestion that bias may be density dependent for fixed-wing survey estimates of red kangaroo density is of concern, although the overall population trends were moderately well tracked by fixed-wing surveys. Furthermore, Cairns (1999) reported no effect of density when assessing bias across regions.

In contrast to the two kangaroo species, wallaroo trends have been poorly tracked and this is reflected in the large variation among the correction factors. Some of this variability may again come from the helicopter surveys, which are known to underestimate wallaroo density. However, comparisons with ground surveys suggest wallaroo density estimates derived from helicopter line transects are no less precise than for reds or greys (Clancy *et al.* 1997). Species identification is a potential problem at Blackall (Grigg *et al.* 1997; Clancy 1999), with relatively high densities of all three species and a large overlap in their habitat use. It is not uncommon to be counting aggregations of all three species. These problems highlight the value of helicopter surveys of kangaroos in areas such as Blackall.

The greater year-to-year variation of correction factors for eastern grey kangaroos for the narrower strip was surprising. It may simply be the greater "edge effect" (the ratio of edge to area) associated with narrower strips (Krebs 1989). Observers may find it harder to maintain a constant transect width at the narrower strip as they look both behind and in front of the aircraft with changing survey direction, and as survey height fluctuates. The fact that observers were trained originally to scan 200 m strips could exacerbate this problem. The reduced variation among correction factors for wallaroos may be because they become more prominent in the narrower strip. Species identification in general is also better in the narrower strip. The reason for the different CVs of the two strip widths is not clear, but the sample size is small and the difference may be peculiar to the Blackall region. Further comparisons involving both strip widths are needed and are planned in New South Wales (Gilroy 1999).

There has been a great reluctance to alter a survey method that has collected population estimates in a standard form for greater than 20 years in some cases. Use of the standard correction factors made some improvement to repeatability, but the resultant density estimates were still short of true density. From these and other preliminary data (Pople *et al.* 1998a; Cairns 1999), the argument for a shift to species-specific, regional correction factors is strong. Future assessments of bias and repeatability of fixed-wing aerial surveys in New South Wales (Gilroy 1999) and Queensland (Lundie-Jenkins *et al.* 1999) will assess the generality of many of these results.

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